Thermo

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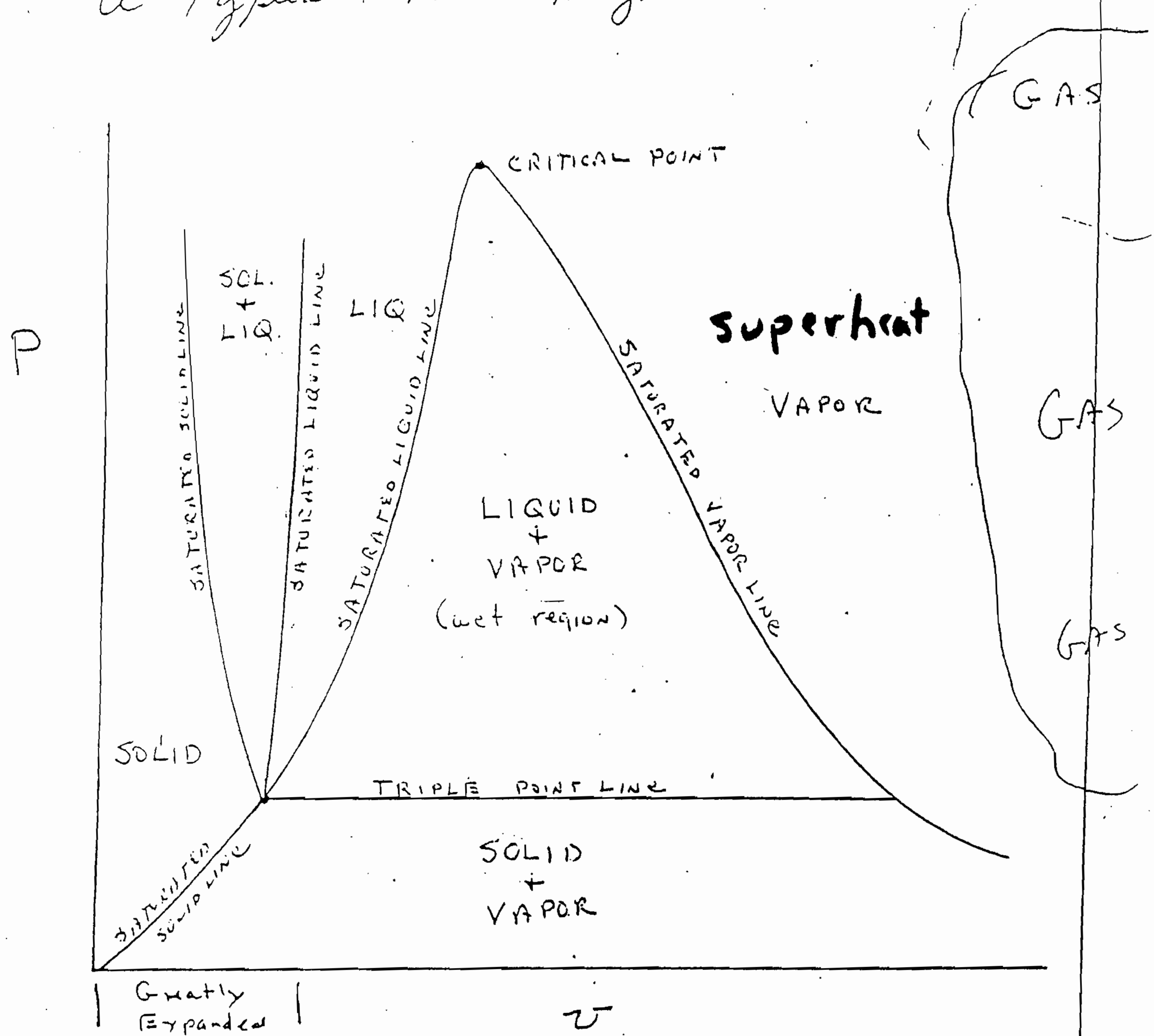
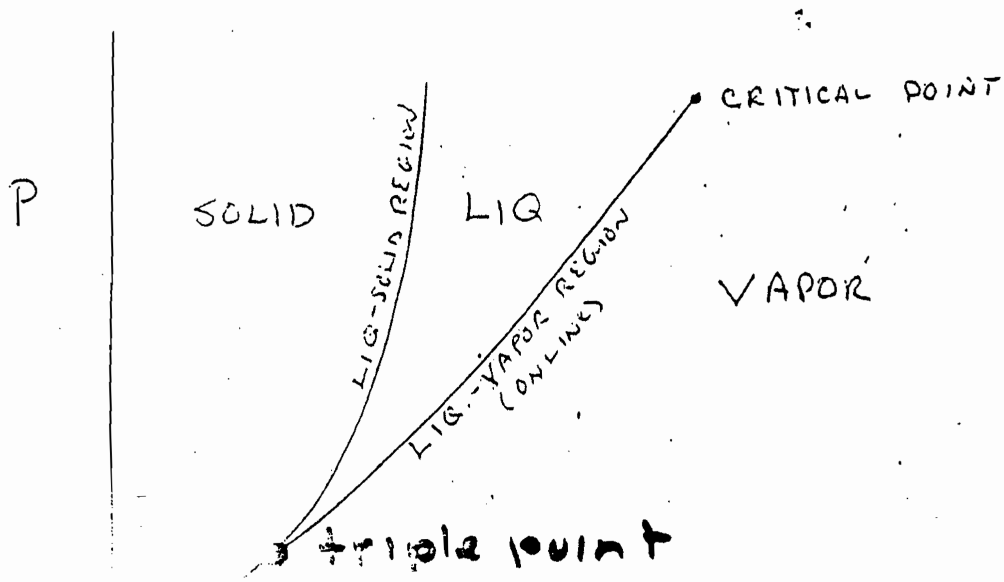
Mechanical PE Review

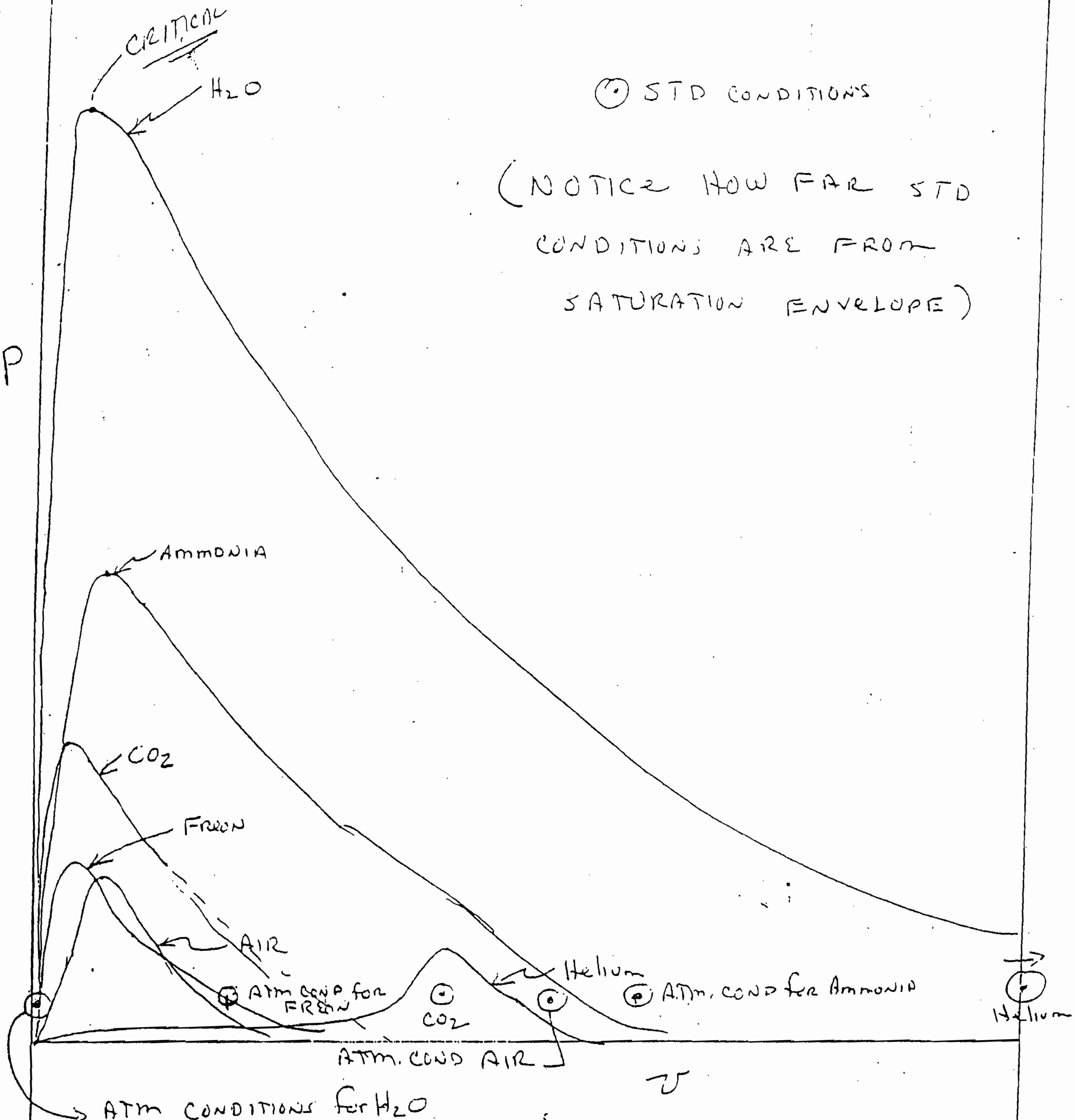
Center for Continuing Engineering Education (C2E2)

A Typical Phase Diagram





Comparison of Saturated Curves for Various Substances



	P_c (psia)	v_c (ft^3/lbm)	T_c (°F)	v_c @ T+P STD
H_2O	3205	.0498	705	.016 lbm/ft^3
Ammonia	1635	.0652	270	22 "
CO_2	1073	.0344	88	4.8 lbm/ft^3
Freon 12	582	.0293	232	3 lbm/ft^3
Air	[illegible]	[illegible]	[illegible]	

THERMODYNAMICS

1st and 2nd Law Formulae for Reversible Processes of an Ideal Gas (per unit mass basis)* (with Constant Specific Heats)

PROCESS	CLOSED SYSTEM (NON-FLOW)	OPEN SYSTEM (STEADY FLOW)	
General ($pv = RT$) $\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2}$	$q = Cv\ (T_2 - T_1) + w$ $w = \int_1^2 p\,dv$ $s_2 - s_1 = Cp \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1}$ $\longleftrightarrow$	$q = Cp\ (T_2 - T_1) + \Delta KE + \Delta PE + w$ $w = -\int_1^2 v\,dP - \Delta KE - \Delta PE$ $= Cv \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}$	$s_2 - s_1$ is the same for closed or open systems
POLYTROPIC $pv^n = \text{const}$ $\frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{n/n-1} = \left(\frac{v_1}{v_2}\right)^{n}$ $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{n-1/n} = \left(\frac{v_1}{v_2}\right)^{n-1}$ $\frac{v_2}{v_1} = \left(\frac{P_1}{P_2}\right)^{1/n} = \left(\frac{T_1}{T_2}\right)^{1/n-1}$	$q = \frac{k-n}{1-n}\ Cv(T_2 - T_1)$ $w = \frac{k-1}{1-n}\ Cv(T_2 - T_1)$ $s_2 - s_1 = Cp \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1}$ $\longleftrightarrow$	$q = \frac{k-n}{1-n}\ Cv(T_2 - T_1)$ $w = n\ \frac{k-1}{1-n}\ Cv(T_2 - T_1) - \Delta KE - \Delta PE$ $= Cv \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}$	$s_2 - s_1$ is the same for closed or open systems
Constant Volume (Isometric) $v_2 = v_1$ $n = \infty$ $\frac{P_2}{T_2} = \frac{P_1}{T_1}$	$q = Cv\ (T_2 - T_1)$ $w = 0$ $s_2 - s_1 = Cv \ln (T_2/T_1)$	$q = Cv\ (T_2 - T_1)$ $w = -v(P_2 - P_1) - \Delta KE - \Delta PE$ $s_2 - s_1 = Cv \ln (T_2/T_1)$	

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PROCESS	CLOSED SYSTEM	OPEN SYSTEM
Constant Pressure (Isobaric) $P_2 = P_1 \quad n = 0$ $\frac{v_2}{T_2} = \frac{v_1}{T_1}$	$q = Cp\ (T_2 - T_1)$ $w = p\ (v_2 - v_1)$ $w = R\ (T_2 - T_1)$ $s_2 - s_1 = Cp \ln (T_2/T_1)$	$q = Cp\ (T_2 - T_1)$ $w = -\Delta KE - \Delta PE$ $s_2 - s_1 = Cp \ln (T_2/T_1)$
Const. Temperature (Isothermal) $T_2 = T_1 \quad n = 1$ $P_2 v_2 = P_1 v_1$	$q = w = T(s_2 - s_1)$ $q = w = RT \ln \frac{v_2}{v_1}$ or $\frac{P_1}{P_2}$ $s_2 - s_1 = R \ln \frac{v_2}{v_1}$ or $\frac{P_1}{P_2}$	$q = T(s_2 - s_1) = RT \ln \frac{v_2}{v_1}$ or $\frac{P_1}{P_2}$ $w = RT \ln \frac{v_2}{v_1}$ or $\frac{P_1}{P_2} - \Delta KE - \Delta PE$ $s_2 - s_1 = R \ln \frac{v_2}{v_1}$ or $\frac{P_1}{P_2}$
ADIABATIC (Isentropic) $n = k$ $s_2 = s_1$	$q = 0$ $w = Cv\ (T_1 - T_2)$ $w = \frac{P_1 v_1 - P_2 v_2}{k-1}$ $w = R(T_1 - T_2)/k-1$ $s_2 - s_1 = 0$	$q = 0$ $w = cp\ (T_1 - T_2) - \Delta KE - \Delta PE$ $w = \frac{k(P_1 v_1 - p_2 v_2)}{k-1} - \Delta KE - \Delta PE$ $w = KR(T_1 - T_2)/k-1 - \Delta KE - \Delta PE$ $s_2 - s_1 = 0$

*Constant (Average) Specific Heats (Cv, Vp) assumed. $R = Cp - Cv$, $k = Cp/Cv$, $Cp = kR/(k-1)$, $Cv = R/(k-1)$

$\Delta u = u_2 - u_1 = Cv\ (T_2 - T_1)$, $\quad \Delta h = h_2 - h_1 = Cp\ (T_2 - T_1)$

$\Delta KE = \frac{\vec{V}_2^{\,2} - \vec{V}_1^{\,2}}{2g_c \times 1000}$ $\quad \Delta PE = \frac{g(z_2 - z_1)}{g_c \times 1000}$

NOTE: ΔKE and ΔPE may be negligible for many open systems

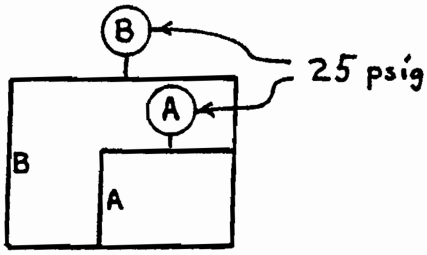
Problem *2.1

Referring to Figure 2.10 in the text, the atmospheric pressure is 100 kPa and the pressure gages A and B read 25 psig. Determine the absolute pressures in boxes A and B in (a) psia; (b) in. Hg absolute.

Given: Atmospheric pressure and readings of gages A and B.

Find: The absolute pressures in boxes A and B.

Sketches and Given Data:



$P_{surr} = 100$ kPa

Assumptions: None

Analysis: Convert atmospheric pressure to psia.

$$(100\ \text{kPa})\left(\frac{1\ \text{psi}}{6.8948\ \text{kPa}}\right) = 14.5\ \text{psia}$$

Determine pressures A and B in psia, then convert to in Hg absolute.

a) $$P_{B_{abs}} = P_{B_{gage}} + P_{surr}$$

$$= 25\ \text{psia} + 14.5\ \text{psia} = 39.5\ \text{psia}$$

$$P_{A_{abs}} = P_{A_{gage}} + P_{surr_A} \text{ but } P_{surr_A} = P_{B_{abs}}$$

$$= 25\ \text{psia} + 39.5\ \text{psia} = 64.5\ \text{psia}$$

b) $$P_{B_{abs}} = (39.5\ \text{psia})\left(\frac{1\ \text{inHg}}{0.4912\ \text{psia}}\right) = 80.42 \text{ in Hg absolute}$$

$$P_{A_{abs}} = (64.5\ \text{psia})\left(\frac{1\ \text{inHg}}{0.4912\ \text{psia}}\right) = 131.3 \text{ in Hg absolute}$$

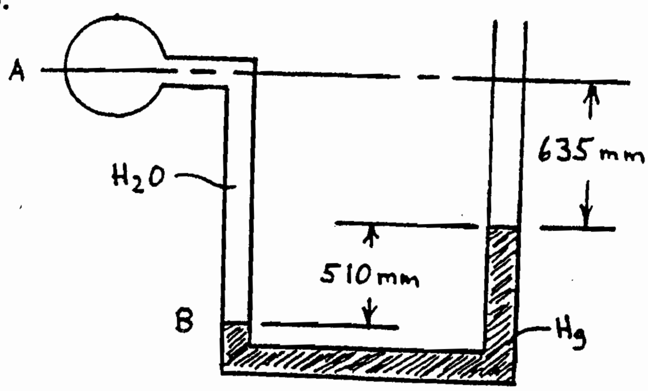
Problem *2.6

Determine the pressure at points A and B if the density of mercury is 724.4 lbm/ft^3 and that of water is 62.4 lbm/ft^3. Refer to sketch for problem 2.16 (SI).

Given: Fluid densities and heights.

Find: Pressures at points A and B.

Sketch and Given Data:



ρ_{H_2O} = 62.4 lb_m/ft^3

ρ_{Hg} = 724.4 lb_m/ft^3

Assumptions:
1) Atmospheric pressure is 14.696 psia
2) Acceleration of gravity is 32.1739 ft/sec^2.

Analysis: Converting heights to feet.

$$(635\text{ mm})\left(\frac{1\text{ in}}{25.4\text{ mm}}\right)\left(\frac{1\text{ ft}}{12\text{ in}}\right) = 2.083\text{ ft}$$

$$(510\text{ mm})\left(\frac{1\text{ in}}{25.4\text{ mm}}\right)\left(\frac{1\text{ ft}}{12\text{ in}}\right) = 1.673\text{ ft.}$$

Pressure at B is atmospheric plus 1.673 ft column of mercury.

$$P_B = P_{surr} + \frac{\rho L g}{g_c} = 14.696\text{ psia} + \frac{(724.4\text{ lbm/ft}^3)(1.673\text{ ft})(32.1739\text{ ft/sec}^2)}{(144\text{ in}^2/\text{ft}^2)(32.1739\text{ lbm-ft/lb}_f\text{-sec}^2)}$$

$$= 23.1\text{ psia}$$

Pressure at A is pressure at B minus 3.756 ft column of water.

$$P_A = P_B - \frac{\rho L g}{g_c} = 23.1\text{ psia} = \frac{(62.4\text{ lbm/ft}^3)(3.756\text{ ft})(32.1739\text{ ft/sec}^2)}{(144\text{ in}^2/\text{ft}^2)(32.1739\text{ lbm-ft/lb}_f\text{-sec}^2)}$$

$$= 21.5\text{ psia}$$

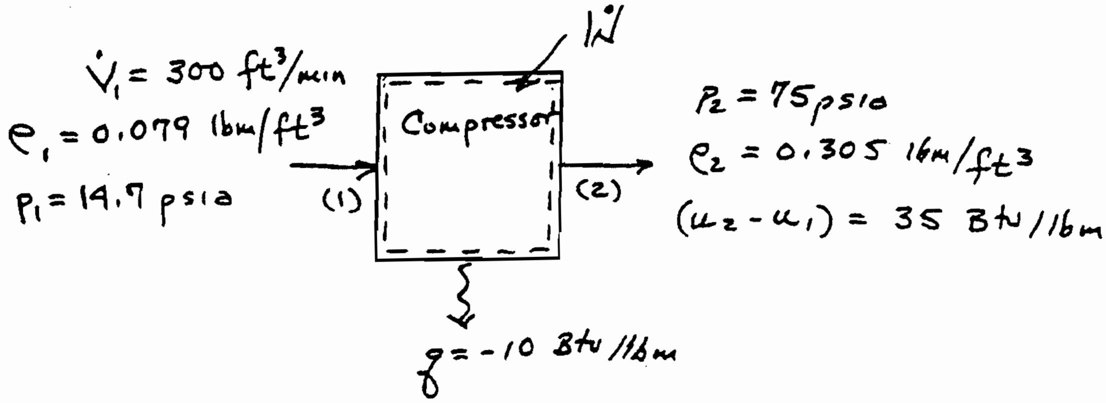
Problem *3.5

An air compressor handles 300 ft^3/min of air with a density of 0.079 lbm/ft^3 and a pressure of 14.7 psia, and it discharges at a pressure of 75 psia with a density of 0.305 lbm/ft^3. The change in specific internal energy across the compressor is 35 Btu/lbm, and the heat loss by cooling is 10 Btu/lbm. Neglecting changes in kinetic and potential energies, find the power in Btu per hour, horsepower, and kilowatts.

Given: A compressor receives a steady flow of air through it. The inlet and discharge are given.

Find: The power required.

Sketch & Given Data:



Assumptions:

1) The compressor is a steady-state open system.

2) Neglect kinetic and potential energies.

Analysis: The first law for a steady-state open system is:

$$\dot{Q} + \dot{m}(u+p/\rho+ke+pe)_1 = \dot{W} + \dot{m}(u+p/\rho+ke+pe)_2$$

Apply assumption (2):

$$\dot{Q} + \dot{m}(u+p/\rho)_1 = \dot{W} + \dot{m}(u+p/\rho)_2$$

$$\dot{Q} + \dot{m}p_1/\rho_1 = \dot{W} + \dot{m}[(u_2-u_1)+p_2/\rho_2]$$

The mass flowrate is not given, so it must be found from volume flowrate.

$$\dot{m} = \rho_1 \dot{V}_1 = \left(0.079\frac{\text{lbm}}{\text{ft}^3}\right)\left(300\frac{\text{ft}^3}{\text{min}}\right) = 23.7\frac{\text{lbm}}{\text{min}}$$

The heat flux, is $\dot{Q} = \dot{m}q$. Substitute data in the first law equation.

$$\left(-10\frac{\text{Btu}}{\text{lbm}}\right)\left(23.7\frac{\text{lbm}}{\text{min}}\right) + \left(23.7\frac{\text{lbm}}{\text{min}}\right)\left(14.7\frac{\text{lb}_f}{\text{in}^2}\right)\left(144\frac{\text{in}^2}{\text{ft}^2}\right)\left(\frac{1}{0.079}\frac{\text{ft}^3}{\text{lbm}}\right)\left(\frac{1\ \text{Btu}}{778.16\ \text{ft-lb}_f}\right) =$$

$$\dot{W} + \left(23.7\frac{\text{lbm}}{\text{min}}\right)\left[\left(89.7\frac{\text{lb}_f}{\text{in}^2}\right)\left(144\frac{\text{in}^2}{\text{ft}^2}\right)\left(\frac{1\text{ft}^3}{0.305\ \text{lbm}}\right)\left(\frac{1\text{Btu}}{778.16\ \text{ft-lb}_f}\right) + (35\ \text{Btu/lbm})\right]$$

$$\dot{W} = -1540\frac{\text{Btu}}{\text{min}} = -92{,}415\frac{\text{Btu}}{\text{hr}} = -36.3\ \text{hp} = -27.1\ \text{kW}$$

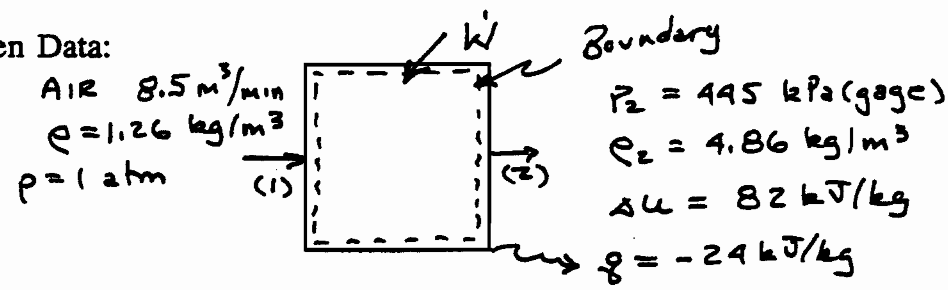
Problem 3.12

An air compressor handles 8.5 m^3/min of air with a density of 1.26 kg/m^3 and a pressure of 1 atm, and it discharges at 445 kPa (gage) with a density of 4.86 kg/m^3. The change in specific internal energy across the compressor is 82 kJ/kg and the heat loss by cooling is 24 kJ/kg. Neglecting changes in kinetic and potential energies, find the power in kilowatts.

Given: The volume flowrate of air entering a compressor at specified conditions, the heat loss from the compressor and the specified air conditions leaving the compressor.

Find: The power required for the compressor.

Sketch & Given Data:



Assumptions:

1) The air compressor is a steady-state open system.

2) Neglect changes in kinetic and potential energies.

Analysis: The first law for an open, steady-state system is:

$$\dot{Q} + \dot{m}\,[u + p/\rho + ke + pe]_1 = \dot{W} + \dot{m}\,[u + p/\rho + ke + pe]_2$$

The mass flowrate of air can be determined from:

$$\dot{m} = \rho_1 \dot{V}_1 = (1.26\ \text{kg/m}^3)\left(8.5\frac{\text{m}^3}{\text{min}}\right)\left(\frac{1\ \text{min}}{60\ \text{sec}}\right)$$

$$\dot{m} = 0.1785\ \text{kg/s}$$

Apply assumption (2) to the first law and substitute into the resulting equation.

$$(-24k\ J/kg)(0.1785\ kg/s) + (0.1785\ kg/s)\left[(u_1\ kJ/kg) + (101.3\frac{kN}{m^2})(\frac{1}{1.26}\frac{m^3}{kg})\right]$$

$$= \dot{W}(kW) + (0.1785 kg/s)\left[\left(u_2\frac{kJ}{kg}\right) + \left(546.3\frac{kN}{m^2}\right)\left(\frac{1}{4.86}\frac{m^3}{kg}\right)\right]$$

$$u_2 - u_1 = 82\ kJ/kg$$

The power is

$$\dot{W} = \underline{-24.6\ kW}$$

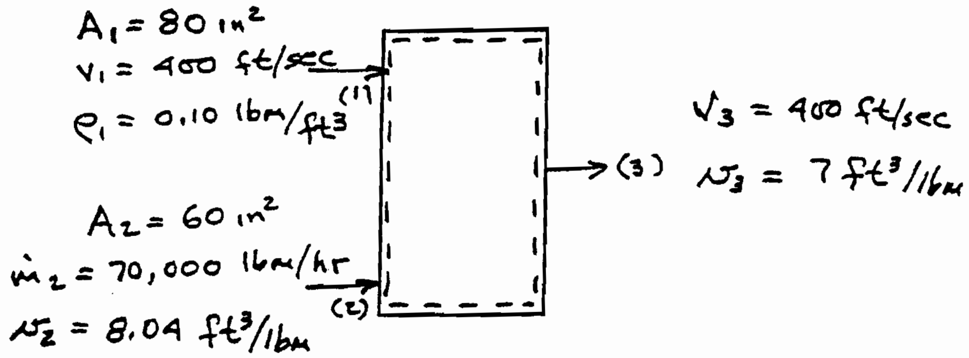
Problem *3.6

Two gaseous streams containing the same fluid enter a mixing chamber and leave as a single stream. For the first gas the entrance conditions are $A_1 = 80$ in.^{2}, $v_1 = 400$ ft/sec, $\rho_1 = 0.10$ lbm/ft^3. For the second gas the entrance conditions are $A_2 = 60$ in.^{2}, $\dot{m}_2 = 70{,}000$ lbm/hr, $v_2 = 8.04$ ft^3/lbm. The exit stream condition is $v_3 = 400$ ft/sec, and $v_3 = 7$ ft^3/lbm. Determine (a) the total mass flow leaving the chamber; (b) velocity of gas 2.

Given: A mixing chamber receives two fluid streams and discharges a single fluid stream.

Find: The mass flowrate leaving the mixing chamber and the velocity of the second inlet fluid.

Sketch & Given Data:



Assumptions: 1) The mixing chamber is a steady-state open system.

Analysis: The information given and the questions asked in this problem are related to mass flowrate. Hence, starting with the conservation of mass for steady flow conditions is a wise place to begin.

$$\dot{m}_1 + \dot{m}_2 = \dot{m}_3$$
$$\dot{m} = \rho A v$$

In this case $\dot{m}_1$ is not known, so solve for it.

$$\dot{m}_1 = \left(0.10\frac{\text{lbm}}{\text{ft}^3}\right)\left(\frac{80\text{in}^2}{144\text{in}^2/\text{ft}^2}\right)\left(400\frac{\text{ft}}{\text{sec}}\right) = 22.22\frac{\text{lbm}}{\text{sec}}$$

$$\dot{m}_1 = 80{,}000\frac{\text{lbm}}{\text{hr}}$$

a) $\dot{m}_3 = 80{,}000 + 70{,}000 = \underline{150{,}000 \text{ lbm/hr}}$

The velocity of gas 2 is found from the conservation of mass equation.

$$\dot{m}_2 = \rho_2 A_2 v_2$$

$$\left(19.44 \frac{\text{lbm}}{\text{sec}}\right) = \left(\frac{1 \text{ lbm}}{8.04\text{ft}^3}\right)\left(\frac{60\text{in}^2}{144\text{in}^2/\text{ft}^2}\right)(v_2 \text{ ft/sec})$$

b) $v_2 = \underline{375.2 \text{ ft/sec}}$

Problem *3.7

Steam with a flow rate of 3000 lbm/hr enters an adiabatic nozzle at 200 psia, 600 ft/min, with a specific volume of 2.36 ft³/lbm, and with a specific internal energy of 1122.7 Btu/lbm. The exit conditions are p = 20 psia, specific volume = 17.6 ft³/lbm, and internal energy = 973 Btu/lbm. Determine the exit velocity.

Given: A nozzle receives a steady flow of steam, increasing its velocity. The steam states into and from the nozzle are known.

Find: The steam's exit velocity.

Sketch & Given Data:

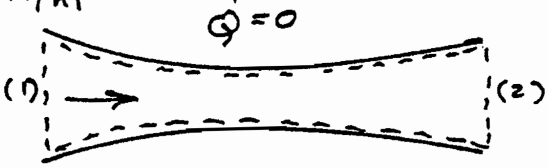
$\dot{m} = 3000$ lbm/hr

$p_1 = 200$ psia

$V_1 = 600$ ft/min

$v_1 = 2.6$ ft³/lbm

$u_1 = 1122.7$ Btu/lbm



$p_2 = 20$ psia

$v_2 = 17.6$ ft³/lbm

$u_2 = 973$ Btu/lbm

Assumptions:

1) The nozzle is a steady-state open system.

2) Neglect changes in potential energy.

3) The heat and work transfer are zero.

Analysis: The first law for a steady-open system is

$$\dot{Q} + \dot{m}(u+pv+ke+pe)_1 = \dot{W} + \dot{m}(u+pv+ke+pe)_2$$

Apply assumptions 2 and 3 and divide by the mass flowrate, yielding

$$u_1 + p_1 v_1 + ke_1 = u_2 + p_2 v_2 + ke_2$$

Substitute the data into the equation

$$\left(1122.7\frac{\text{Btu}}{\text{lbm}}\right) + \left(200\frac{\text{lb}_f}{\text{in}^2}\right)\left(144\frac{\text{in}^2}{\text{ft}^2}\right)\left(2.36\frac{\text{ft}^3}{\text{lbm}}\right)\left(\frac{1}{778.16(\text{ft-lb}_f)/\text{Btu}}\right)$$

$$+ \frac{(10\text{ft/sec})^2}{(2)\left(32.174\frac{\text{lbm-ft}}{\text{lf}_f\text{-sec}^2}\right)\left(778.16\frac{\text{ft-lb}_f}{\text{Btu}}\right)}$$

$$= (973\ \text{Btu/lbm}) + \frac{\left(20\frac{\text{lb}_f}{\text{in}^2}\right)(144\text{in}^2/\text{ft}^2)(17.6\text{ft}^3/\text{lbm})}{(778.16\ \text{ft-lb}_f/\text{Btu})} + ke_2$$

$$ke_2 = 171.9\frac{\text{Btu}}{\text{lbm}}$$

$$\frac{1}{2}\frac{(v_2\ \text{ft/sec})^2}{\left(32.174\frac{\text{lbm-ft}}{\text{lb}_f\text{-sec}^2}\right)(778.16\ \text{ft-lb}_f/\text{Btu})} = 171.9\frac{\text{Btu}}{\text{lbm}}$$

$$v_2 = \underline{2934\ \text{ft/sec}}$$

Problem *3.22

A 1500 W electric hair dryer is essentially an adiabatic duct and consists of a small fan which blows air over a heating element, increasing the temperature of the air from its inlet temperature of 77 F to an exit temperature of 127 F. The air density at inlet conditions is 0.0739 lbm/ft^3 and at outlet conditions is 0.0709 lbm/ft^3. The specific internal energy changes from 91.5 Btu/lbm at inlet to 100.1 Btu/lbm at outlet. The pressure remains constant at 14.7 psia throughout the hair dryer. The exit cross-sectional area of the hair dryer when the nozzle is in place is 1 in^2. Determine:

a) The mass flowrate of air through the dryer;

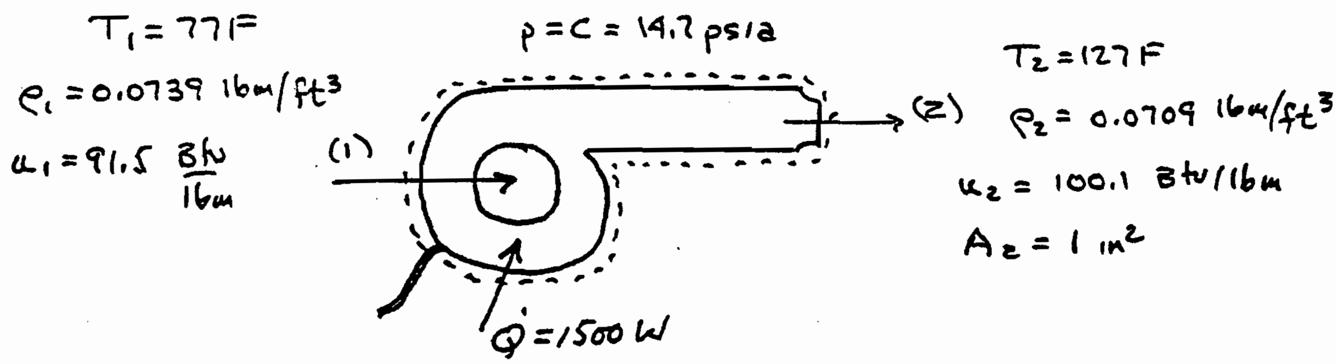
b) The volume flowrate of air at inlet conditions;

c) The velocity of the air leaving the nozzle.

Given: An electric hair dryer with inlet and outlet air conditions as well as exit nozzle area.

Find: The air mass and volume flowrates and the exit air velocity.

Sketch & Given Data:



Assumptions:

1) Steady state, steady flow.

2) Neglect potential energy.

3) The power of fan is negligible compared to heating element.

4) When the nozzle is not in place, the inlet and exit velocities are essentially the same, hence the change of kinetic energy is zero.

Analysis: a) The first law for an open system for part (a) is

$$\dot{Q} + \dot{m}(u+p/\rho+ke+pe)_1 = \dot{W} + \dot{m}(u+p/\rho+ke+pe)_2$$

Applying assumptions (2), (3), (4) yields:

$$\dot{Q} = \dot{m}[(u_2-u_1)+(p_2/\rho_2-p_1/\rho_1)]$$

$$(1.5\text{kW})\left(56.87\frac{\text{Btu}}{\text{min-kW}}\right) = (\dot{m}\ \text{lbm/min})[(100.1-91.5\ \text{Btu/lbm}) +$$

$$\frac{(14.7\text{lb}_f/\text{in}^2)(144\text{in}^2/\text{ft}^2)}{\left(778.16\frac{\text{ft-lb}_f}{\text{Btu}}\right)}\left[\left(\frac{1}{0.0709\ \text{lbm/ft}^3}\right)-\left(\frac{1}{0.0739\ \text{lbm/ft}^3}\right)\right]$$

$$85.305 = (\dot{m})[8.6 + 1.55]$$

$$\dot{m} = \underline{8.4\ \text{lbm/min}}$$

b) The volume flowrate at inlet conditions is

$$\dot{V}_i = \dot{m}v_i = \dot{m}(1/\rho_i) = (8.4\ \text{lbm/min})\left(\frac{1}{(0.0739\text{lbm/ft}^3)}\right)$$

$$\dot{V}_i = \underline{113.7\ \text{ft}^3/\text{min}}$$

c) The velocity leaving the in² nozzle is found from the conservation of mass.

$$\dot{m} = \rho_2 A_2 v_2$$

$$(8.4\ \text{lbm/min}) = \left(0.0709\frac{\text{lbm}}{\text{ft}^3}\right)(1\ \text{in}^2)\left(\frac{1}{144\ \text{in}^2/\text{ft}^2}\right)(v_2\ \text{ft/min})$$

$$V_2 = 17060\ \text{ft/min} = 284.3\ \text{ft/sec}$$

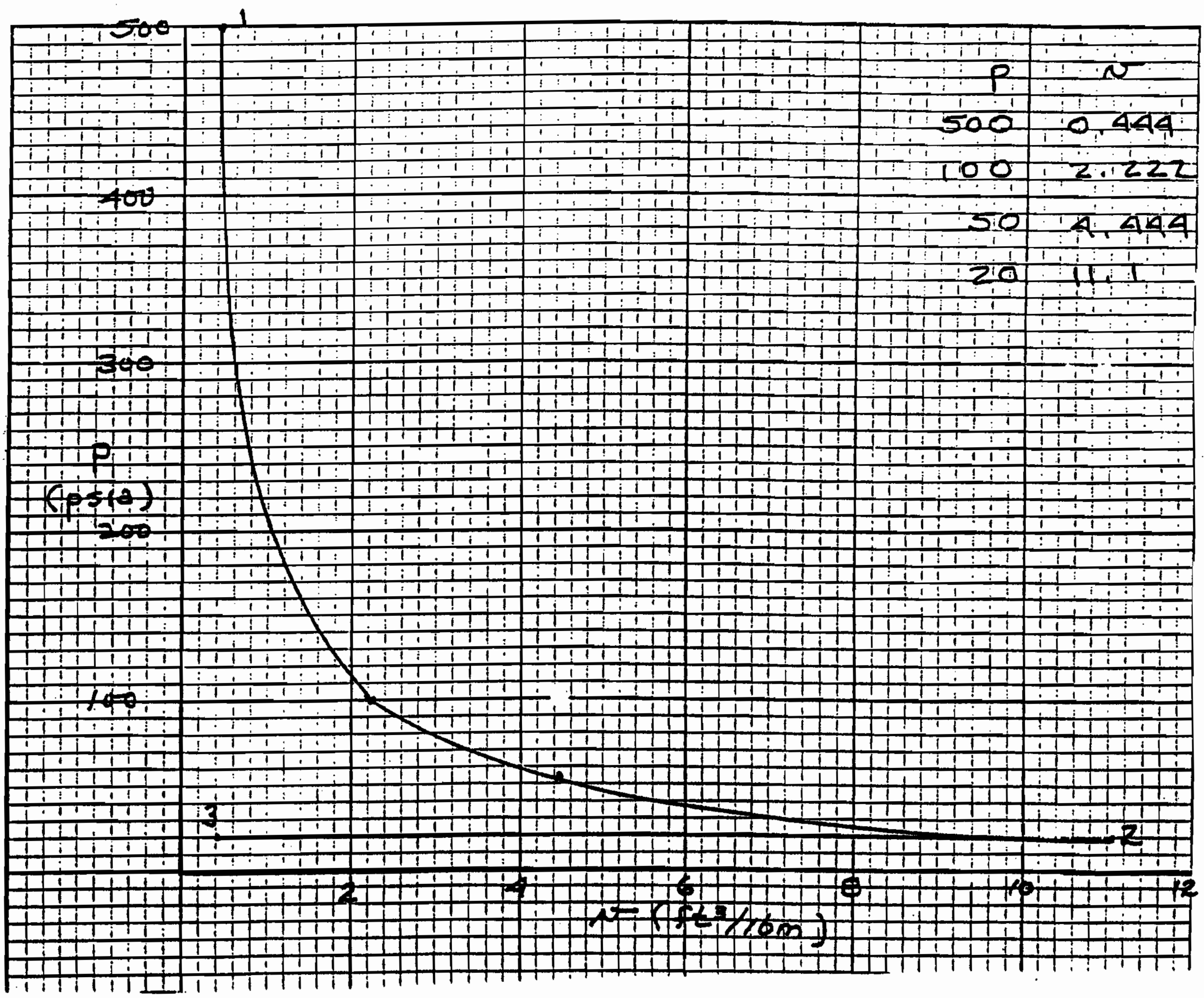
Problem *3.27

Air contained in a piston cylinder undergoes two processes in series. In the first the air expands according to $pv = C$ from 500 psia and a specific volume of 0.444 ft³/lbm to a pressure of 20 psia. The second process is a constant pressure compression until specific volume three equals specific volume one. Sketch the precesses on a pv diagram and determine the work per unit mass.

Given: Air in a piston cylinder undergoes two defined processes, one after the other.

Find: Sketch the processes on a pv diagram and determine the work in Btu/lbm.

Sketch & Given Data:



Assumptions:
1) The air in the piston/cylinder is a closed system.
2) Neglect kinetic and potential energies.
3) The processes are quasi-equilibrium ones.

Analysis: Find the work for each process and add them together. The work for process 1-2 is

$$W_{1-2} = \int p dv = \int c \frac{dv}{v} = c \ln\left(\frac{v_2}{v_1}\right) = p_1 v_1 \ln\left(\frac{v_2}{v_1}\right)$$

$$p_2 v_2 = p_1 v_1 \quad \text{hence} \quad v_2/v_1 = p_1/p_2 \qquad v_2 = 25 v_1$$

$$W_{1-2} = p_1 v_1 \ln\left(\frac{p_1}{p_2}\right) = \frac{\left(500\frac{\text{lb}_f}{\text{in}^2}\right)\left(144\frac{\text{in}^2}{\text{ft}^2}\right)\left(0.444\frac{\text{ft}^3}{\text{lbm}}\right)\ln\left(\frac{500}{20}\right)}{(778.16 \text{ ft-lb}_f/\text{Btu})}$$

$$W_{1-2} = 132.2 \text{ Btu/lbm}$$

For the process 2-3 the work is

$$W_{2-3} = \int p dv = p(v_3 - v_2) = \frac{\left(20\frac{\text{lb}_f}{\text{in}^2}\right)\left(144\frac{\text{in}^2}{\text{ft}^2}\right)(0.444 - 11.1 \text{ ft}^3/\text{lbm})}{(778.16 \text{ ft-lb}_f/\text{Btu})}$$

$$W_{2-3} = -39.4\frac{\text{Btu}}{\text{lbm}}$$

$$W_{3-1} = 0 \quad \text{for} \quad v = c$$

The net work is

$$W_{net} = 132.2 - 39.4 = 92.8 \text{ Btu/lbm}$$

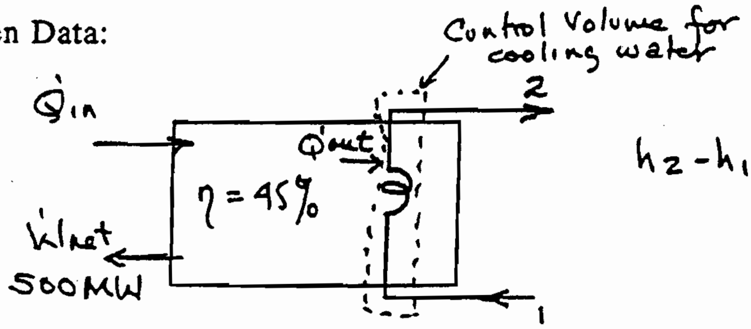
Problem *3.41

A power plant produces 500 MW of electric power while operating with an efficiency of 45%. The heat rejected from the cycle goes into cooling water supplied from an adjacent river. The water's enthalpy increases by 20 Btu/lbm as it receives the heat rejected. Determine the mass flowrate of water required.

Given: A power plant produces a given amount of power at a known efficiency. In doing so the heat flow from the plant enters a river.

Find: The flowrate of water required for cooling.

Sketch & Given Data:



$h_2 - h_1 = 20$ Btu/lbm

Assumptions:

1) The cycle is a closed system.

2) Neglect changes in kinetic and potential energy of the cooling water and there is no work done in the cooling process.

Analysis: For a power producing cycle,

$$\eta_{Th} = \frac{\dot{W}net}{\dot{Q}in}$$

$$0.45 = \frac{500}{\dot{Q}in}$$

$$\dot{Q}in = 1111.1 \text{ MW}$$

For any cycle:

$$\dot{W}net = \dot{Q}in + \dot{Q}out$$

$$500 = 1111.1 + \dot{Q}out$$

$$\dot{Q}out = -611.1MW$$

$$\dot{Q}out = (-611.1MW)\left(1000\frac{kW}{MW}\right)\left(3412.2\frac{Btu}{hr\text{-}kW}\right) = 2.0852 \times 10^{9}\frac{Btu}{hr}$$

From a first law analysis on the cooling water (where the heat is entering the cooling water; hence positive from the water's view).

$$\dot{Q} + \dot{m}(h+ke+pe)_1 = \dot{W} + \dot{m}(h+ke+pe)_2$$

Apply assumption (2)

$$\dot{Q} + \dot{m}h_1 = \dot{m}h_2$$

$$\left(2.0852 \times 10^{9}\frac{Btu}{hr}\right) = \left(\dot{m}\frac{lbm}{hr}\right)\left(20\frac{Btu}{lbm}\right)$$

$$\dot{m} = \underline{1.042 \times 10^{8}\frac{lbm}{hr}}$$

Problem *4.1

Fill in the data omitted in the following table for water.

	Pressure (psia)	Temperature (°F)	Specific volume (ft³/lbm)	Enthalpy (Btu/lbm)	Quality x(%)	State
(a)	500		0.650			
(b)		250		1000		
(c)	600	700				
(d)	800			1399.1		
(e)		300			90	
(f)	1000	200				

Indicate for each state whether the state is subcooled liquid, saturated liquid, mixture, saturated vapor or superheated vapor.

Given: Two independent steam properties.

Find: Remaining properties and state of steam.

Assumption: 1) The water is in equilibrium.

Analysis: (a) Using Appendix A.15 at 500 psia, specific volume is between v_f and v_g, therefore this is a mixture. From Appendix A.15.

$T = 467.02°F$ $\qquad h_f = 449.67$ Btu/lbm

$v_f = 0.019739$ ft³/lbm $\qquad h_{fg} = 755.64$ Btu/lbm

$v_g = 0.92849$ ft³/lbm

$$v = v_f + x(v_g - v_f)$$

$$0.65 \text{ ft}^3/\text{lbm} = 0.019739 \text{ ft}^3/\text{lbm} + x(0.92849 \text{ ft}^3/\text{lbm} - 0.019739 \text{ ft}^3/\text{lbm})$$

$$x = 0.694$$

$$h = h_f + x\,h_{fg} = 449.67 \text{ Btu/lbm} + (0.694)(755.64 \text{ Btu/lbm})$$

$$= 974.1 \text{ Btu/lbm}$$

(b) Using Appendix A.14 at 250°F, enthalpy is between h_f and h_g, therefore, this is a mixture. From Appendix A.15.

$P = 29.864$ psia $\qquad h_f = 218.66$ Btu/lbm

$v_f = 0.017005$ ft³/lbm $\qquad h_{fg} = 945.59$ Btu/lbm

$v_g = 13.808$ ft³/lbm

$$h = h_f + x\,h_{fg}$$

$$1000 \text{ Btu/lb} = 218.66 \text{ Btu/lbm} + (x)(945.59 \text{ Btu/lbm})$$

$$x = 0.826$$

$$v = v_f + x(v_g - v_f) = 0.017005 \text{ ft}^3/\text{lbm}$$

$$+ (0.826)(13.808 \text{ ft}^3/\text{lbm} - 0.017005 \text{ ft}^3/\text{lbm})$$

$$= 11.41 \text{ ft}^3/\text{lbm}$$

(c) From appendix A.16, since temperature is above saturation for 600 psia, this is a superheated vapor.

$v = 1.0732$ m³/kg $\qquad h = 1351.4$ Btu/lbm

(d) From appendix A.16, since enthalpy is above h_g for 800 psia, this is a superheated vapor.

$T = 800$°F $\qquad v = 0.87629$ ft³/lbm

(e) Since quality is given, this is a mixture. From Appendix A.14.

$p = 67.078$ psia $\qquad h_f = 269.64$ Btu/lbm

$v_f = 0.017453$ ft³/lbm $\qquad h_{fg} = 910.64$ Btu/lbm

$v_g = 6.4627$ ft³/lbm

$$v = v_f + x(v_g - v_f) = 0.017453 \text{ ft}^3/\text{lbm} + (0.9)(6.4627 \text{ ft}^3/\text{lbm} - 0.017453 \text{ ft}^3/\text{lbm})$$

$$= 5.818 \text{ ft}^3/\text{lbm}$$

$$h = h_f + x\,h_{fg} = 269.64 \text{ Btu/lbm} + (0.9)(910.64 \text{ Btu/lbm})$$

$$= 1089.2 \text{ Btu/lb}$$

(f) Since temperature is below saturation for 1000 psia, this is a subcooled liquid. Using Appendix A.17.

$$v = 0.01658 \text{ ft}^3\text{/lbm} \qquad h = 170.32 \text{ Btu/lbm}$$

	psia	°F	v ft³/lbm	h Btu/lbm	x%	State
(a)	500	467.02	0.65	974.1	69.4	mixture
(b)	29.864	250	11.41	1000	82.6	mixture
(c)	600	700	1.0732	1351.4	100	superheated vapor
(d)	800	800	0.87624	1399.1	100	superheated vapor
(e)	67.078	300	5.818	1089.2	90	mixture
(f)	1000	200	0.01658	170.32	0	subcooled liquid

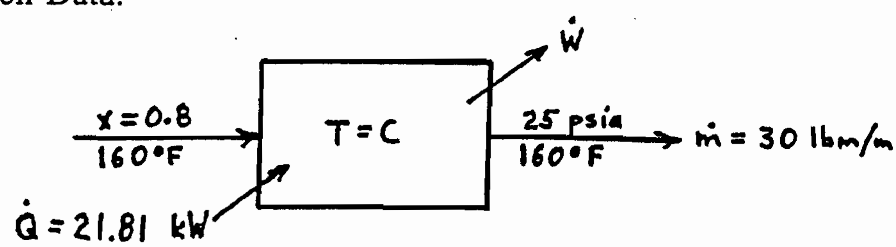
Problem *4.8

Refrigerant 12 is expanded steadily in an isothermal process. The flow rate is 30 lbm/min with an inlet state of wet saturated vapor with an 80% quality to a final state of 160°F and 25 psia. The change of kinetic energy across the device is 1.5 Btu/lbm and the heat added is 21.81 kW. Determine the system power.

Given: R 12 being expanded isothermally with heat addition and change in kinetic energy.

Find: Power.

Sketch & Given Data:



Assumptions:
1) R 12 is in equilibrium.
2) Change in potential energy is negligible.

Analysis: Using Appendix A.20 to find initial enthalpy.

h_f = 46.633 Btu/lbm $\qquad$ h_{fg} = 44.373 Btu/lbm

$$h_1 = h_f + x\,h_{fg} = 46.633 \text{ Btu/lbm} + (0.8)(44.373 \text{ Btu/lbm})$$

$$= 82.131 \text{ Btu/lbm}$$

Using Appendix A.21 to find exit enthalpy.

$$h_2 = 101.234 \text{ Btu/lbm}$$

Writing first law equation for the open system.

$$\dot{Q} + \dot{m}h_1 + \dot{m}\,ke_1 = \dot{W} + \dot{m}h_2 + \dot{m}\,ke_2$$

$$\dot{W} = \dot{Q} + \dot{m}(h_1 - h_2) + \dot{m}(ke_1 - ke_2)$$

$$= (21.81\text{kw})(56.87\text{Btu/kw-min})$$

$$+ (30\text{lbm/m})(82.131\text{Btu/lbm} - 101.234\text{Btu/lbm})$$

$$+ (30\text{lbm/m})(-1.5\text{Btu/lbm})$$

$$= 622.2\text{Btu/m}$$

(a) Writing the first law equation for the closed system.

$Q = \Delta U + W$

$(3\ \text{lbm})(-212.7\ \text{Btu/lbm}) = 38.4\ \text{Btu} + W$

$W = -676.5\ \text{Btu}$

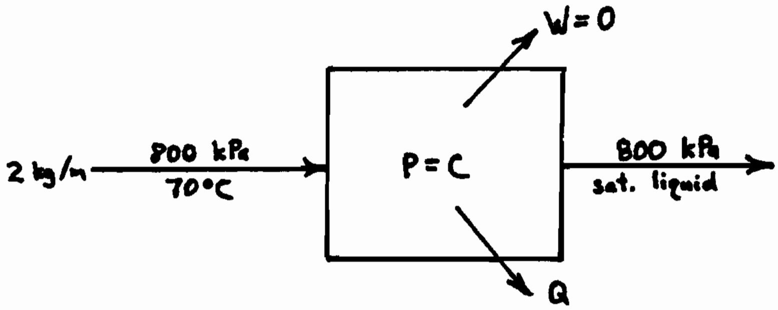
Problem 4.16

Two kilograms per minute of ammonia at 800 kPa and 70°C are condensed at constant pressure to a saturated liquid. There is no change in kinetic or potential energy across the device. Determine (a) the heat; (b) the work; (c) the change in volume; (d) the change in internal energy.

Given: Ammonia is condensed at constant pressure to a saturated liquid.

Find: The heat, work, change in volume and change in internal energy.

Sketch & Given Data:



Assumption: 1) Ammonia is in equilibrium.

Analysis: From Appendix A.10 for 800 kPa and 70°C.

$$v_1 = 0.1991 \text{ m}^3/\text{kg} \quad h_1 = 1598.6 \text{ kJ/kg}$$

$$u_1 = h_1 - P_1 v_1 = 1598.6 \text{ kJ/kg} - (800 \text{ kPa})(0.1991 \text{ m}^3/\text{kg}) = 1439.3 \text{ kJ/kg}$$

From Appendix A.9, interpolating to 800 kPa.

$$v_2 = v_f = 0.001630 \quad h_2 = h_f = 264.7 \text{ kJ/kg}$$

$$u_2 = h_2 - P_2 v_2 = 264.7 \text{ kJ/kg} - (800 \text{ kPa})(0.001630 \text{ m}^3/\text{kg}) = 263.4 \text{ kJ/kg}$$

(a) First law for open system. $\dot{W} = 0.$

$$\dot{Q} + \dot{m}h_1 = \dot{m}h_2$$

$$\dot{Q} = \dot{m}(h_2 - h_1) = \frac{(2\text{kg/min})(264.7\text{kJ/kg} - 1598.6\text{kJ/kg})}{(60\text{sec/min})}$$

$$= -44.5 \text{ kW (heat removed)}$$

(b) $\dot{W} = 0$

(c) $$\Delta\dot{V} = \dot{m}(v_2 - v_1) = (2\ \text{kg/min})(0.001630\text{m}^3/\text{kg} - 0.1991\text{m}^3/\text{kg})$$
$$= -0.395\text{m}^3/\text{min}$$
$$= -0.00658\text{m}^3/\text{s}$$

(d) $$\Delta\dot{U} = \dot{m}(u_2 - u_1) = \frac{(2\ \text{kg/min})(263.4\text{kJ/kg} - 1439.3\text{kJ/kg})}{(60\ \text{sec/min})}$$
$$= -39.2\ \text{kW}$$